

IMAGE SENSOR

Background of the Invention

[0001] The present invention relates to an image sensor composed of a matrix of light sensor circuits, each of which represents a unit pixel and is capable of producing in an photoelectric converting element a sensor current proportional to the quantity of light falling thereon and converting the sensor current into a voltage signal by using a MOS type transistor with a logarithmic output characteristic in a weak inverse state.

[0002] Japanese Laid-open Publication of Unexamined Applications KOKAI No. 219443 (1993) and Japanese Publication of Examined Applications KOKOKU No. 46481 (1995) disclose typical conventional MOS transistor type image sensors, in which a light sensor circuit for one pixel comprises, such as shown in Fig. 1 hereof, a photo-diode PD operating as a photoelectric converting element for producing a sensor current proportional to the quantity of incident light L_s falling thereon, a transistor Q1 having a logarithmic output characteristic in a weak inverse state for converting the sensor current produced in the photodiode into a voltage signal V_{pd} by using the property of its sub-threshold region, a transistor Q2 for amplifying the voltage signal V_{pd} and a transistor Q3 for outputting a sensor signal in accordance with a timing pulse of a readout signal V_s and which is characterized by its a wide dynamic range obtained by giving the output a logarithmic characteristic, thereby achieving the high sensitivity of detecting a light signal.

[0003] However, the prior-art image sensor using light sensor circuits as respective pixels, in which a sensor current proportional to incident light is produced in photo-electric converting element and converted into voltage signal by using a MOS type transistor having logarithmic output characteristic in a weak inverse state, still involves such a problem that it may

suffer the occurrence of unwanted afterglow of each pixel with a decreased quantity of incident illumination falling on the photoelectric converting element.

[0004] The above-mentioned light sensor circuit can produce a sensor current in the transistor Q1 while a sufficient quantity of light L_s is falling on the photodiode PD and can therefore detect a light signal at a response speed sufficient not to produce an afterimage of the pixel owing to a relatively small value of resistance of the transistor Q1. However, the transistor Q1 is set to operate with resistance increased by one order when a current therein decreases by one order. Therefore, decreasing the current flowing in the transistor Q1 with a decrease in the quantity of incident light L_s falling to the photodiode PD causes the transistor Q1 to rapidly increase its resistance. A time constant of the circuit containing a parasitic capacity C (junction capacity plus wiring stray capacity) of the photodiode PD with the increased resistance is increased to elongate time necessary for removing electric charge accumulated in the parasitic capacity C. As a result, an afterimage can be viewed for a longer duration as the quantity of incident light L_s decreases.

[0005] Figure 5 shows characteristics of a variable voltage signal V_{pd} when the sensor current in the photodiode PD rapidly changes from a value $1E-10A$ to a value $1E-15A$ in a conventional sensor system.

[0006] The diagram indicates that, in case of outputting a sensor signal at an interval of $1/30$ seconds, a voltage signal V_{pd} can not be saturated within the above duration with a sensor current $1E-12A$ corresponding to the decreased quantity of the incident light falling on the photodiode PD. In other words, the time necessary for saturating the voltage signal V_{pd} is elongated correspondingly with a decreased value of a sensor current with a decreased quantity of the incident light L_s to the photodiode PD.

[0007] Therefore, if a sensor signal is output in accordance with timing pulses of a reading signal V_s as shown in Fig. 13, an output appears with such an afterglow that may be of a higher level at an earlier time. In Fig. 13, V_{pd}' designates an inverse amplified voltage signal produced by the amplifying transistor Q2 in a conventional sensor system.

SUMMARY OF THE INVENTION

[0008] An object of the present invention is to provide an image sensor composed of an array of light sensor circuits, each of which represents a unit pixel and is capable of producing in a photoelectric converting element a current proportional to the quantity of incident light falling on it and converting the current into a corresponding voltage signal by using a MOS type transistor with a logarithmic output characteristic in a weak inverse state and which is further provided with means for initializing the circuit before detecting a light signal by removing a charge accumulated in a parasitic capacitor of the photoelectric converting element by switching a drain voltage of the transistor from a normal to a lower level for a specified time.

[0009] Another object of the present invention is to provide an image sensor consisting of light sensor circuits arranged to form a matrix of pixels-circuits, each of which is capable of producing in a photoelectric element a current proportional to the quantity of incident light falling on it and converting the current into a corresponding voltage signal by using a MOS type transistor with a logarithmic output characteristic in a weak inverse state. This image sensor is further provided with a voltage switching-over circuit that can change drain voltages of the transistors for all pixels from a normal to a lower level for a specified time to remove charges accumulated in parasitic capacities of respective photoelectric converting elements, thereby initializing all pixels before detecting light signals from them. Therefore, even if the sensor current rapidly decreases with a decreased illumination, each sensor circuit may immediately

obtain a voltage signal corresponding to the incident light quantity at that moment, thereby eliminating the possibility of occurrence of afterglow of the pixel at a decreased quantity of incident light.

[0010] A further object of the present invention is to provide an image sensor consisting of light sensor circuits arranged to form a matrix of plural corresponding pixels, wherein sensor signals are read out (scanned) in a time series in such a manner that pixel lines are successively selected one by one by a pixel-line selecting circuit and pixels in the selected pixel line are successively selected by a pixel selecting circuit, and wherein each pixel in each pixel line to be selected is initialized at the timing adapted to reading each pixel from the line in such a manner that a drain voltage of a MOS transistor for a target pixel is changed by a voltage switching-over circuit from a normal to a lower level for a specified time to remove a charge accumulated in a parasitic capacity of a related photoelectric converting element.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] Figure 1 is an electric circuit diagram of a light sensor circuit for one pixel, which is used as a unit component of an image sensor according to the present invention.

[0012] Figure 2 is a time chart of signals to be generated in the light sensor circuit.

[0013] Figure 3 is a mimic illustration of operation state of a transistor Q1 with a flow of an electric charge (q) therein when initializing the light sensor circuit.

[0014] Figure 4 is a mimic illustration of operation state of a transistor Q1 with a flow of an electric charge (q) therein when detecting a light signal of the light sensor circuit.

[0015] Figure 5 shows characteristic curves of a voltage signal (Vpd) changing with a change of a sensor current of a photodiode (PD) in the light sensor circuit.

[0016] Figure 6 shows characteristic curves of a voltage (V_{pd}) amplifying signal when the light signal reading-out operation is repeated at a specified interval by the light sensor circuit.

[0017] Figure 7 shows output characteristics of pixel signals (V_o) with a change of the quantity of incident light (L_s) falling on a photodiode of the light sensor circuit.

[0018] Figure 8 is a block diagram of an image sensor according to an embodiment of the present invention.

[0019] Figure 9 is a time chart of signals from portions of the image sensor of the present invention.

[0020] Figure 10 is a time chart of signals from portions of the image sensor during the time of simultaneous initialization of all pixels in the image sensor.

[0021] Figure 11 is a block diagram of an image sensor according to another embodiment of the present invention.

[0022] Figure 12 is a time chart of signals from portions of the image sensor of the present invention.

[0023] Figure 13 shows output characteristics of a sensor signal read in accordance with a specified timing pulse at the decreased quantity of incident light falling on a light sensor circuit without initialization of the image sensor.

PREFERRED EMBODIMENTS OF THE PRESENT INVENTION

[0024] Figure 1 illustrates a light sensor circuit representing a unit pixel, which is used as a unit component in an image sensor embodying the present invention.

[0025] The light sensor circuit comprises a photodiode PD for producing a sensor current proportional to the quantity of incident light L_s when detecting a light signal, a transistor Q1 for converting the sensor current flowing in the photodiode PD into a corresponding voltage V_{pd} by

using its logarithmic output characteristic in a weak inverse state, a transistor Q2 for amplifying the voltage signal V_{pd} and a MOS type transistor Q3 for outputting a sensor signal in accordance with a timing pulse of a read-out signal V_s . This sensor is capable of detecting a light signal at a high sensitivity owing to its wide dynamic range achieved by utilizing its logarithmic output characteristic.

[0026] The light sensor circuit according to the present invention is capable of initializing itself before detecting a light signal by removing any electric charge accumulated in a parasitic capacity C of the photodiode PD by changing a drain voltage V_D of the MOS type transistor Q1 to a level lower than a normal for a specified period. For example, without limiting the scope of the present invention, the normal drain voltage in a typical circuit of this type is 2.8V (volts) and the threshold level of transistor Q1 is 0.8V, whereby a "lower" voltage is below 2.0V (i.e. less than $2.8V - 0.8V$). This enables the light sensor circuit to immediately obtain a voltage signal corresponding to the quantity of light falling on it at that time even if a sensor current rapidly changed. Thus, the light sensor circuit may not cause an afterglow of the pixel even with a small quantity of incident light L_s .

[0027] Figure 2 shows a time chart of signals produced at various portions of the light sensor circuit. In Fig. 2, t_1 is the initializing timing pulse and t_2 is the light-signal detection timing pulse. A specified time t_m for which the drain voltage V_D of the transistor Q1 is switched from a normal value (high level H) to a lower voltage value (low level L) and kept at the low level L is set for example to about 5 microseconds in case of reading a pixel at a speed of about 100 nanoseconds. In Fig. 2, T designates a period for accumulating a charge in a parasitic capacity C of the photodiode PD, which period is about 1/30 (or 1/60) sec. for a NTSC signal.

[0028] In the light sensor circuit, once the drain voltage V_D of the MOS type transistor Q_1 was switched over to the low level L for initializing the circuit, the transistor Q_1 is brought into the low-resistance state if a potential between the gate voltage V_G and the drain voltage V_D is greater than a threshold of the transistor Q_1 . Therefore, the source side potential at that moment becomes equal to the drain voltage V_D (a difference between potentials still remains in practice), causing the junction capacity C of the photodiode C to be discharged.

[0029] Figure 3 schematically illustrates the operation of the light sensor circuit by a flow of electric charge q of the transistor Q_1 when initializing the circuit.

[0030] Once the drain voltage V_D of the transistor Q_1 was changed to the normal value (high level H) with an elapse of the time t_m and a light signal was then detected, the source side potential becomes lower than the drain voltage V_D . If the difference between the gate voltage V_G and the drain voltage is larger than the threshold, the MOS type transistor Q_1 reaches the low-resistance state and allows the junction capacity C of the photodiode to be charged again.

[0031] Figure 4 schematically illustrates the operation of the light sensor circuit by a flow of electric charge q of the transistor Q_1 when detecting a light signal. The junction capacity C of the photodiode PD is discharged for initializing the light sensor circuit before detecting a light signal and then charged. In this case, the output voltage V_{pd} (a terminal voltage of the photodiode PD) with an elapse of a specified time from the initializing timing becomes a value corresponding to the quantity of incident light L_s . In other words, the light sensor circuit after initialization can obtain a discharging characteristic with a specified time constant in response to a change in the quantity of incident light.

[0032] In that case, if the light sensor circuit is left as it is for a long time, a current supplied from the drain voltage V_D through the transistor Q_1 becomes equal to a current flowing

in the photodiode PD. The same discharging characteristic can be thus always maintained as far as no charge remains. This eliminates the possibility of afterglow of pixels.

[0033] The light sensor circuit can therefore obtain a sensor signal corresponding to the quantity of incident light L_s with no afterglow of the pixel by detecting a light signal with an elapse of a specified time after initialization of the circuit.

[0034] Figure 5 illustrates the changing characteristics of a voltage signal V_{pd} with a current rapidly changed from $1E-10A$ to $1E-15A$ in the case of detecting a light signal at a moment of $1/30$ sec. after the initialization in a conventional sensor system.

[0035] Figure 6 shows characteristics of the amplified voltage signal V_{pd} when light signals were repeatedly read at an interval of $1/30$ second in the system of this invention. The diagram indicates that the signal characteristics obtained every $1/30$ second corresponds to the sensor current proportional to the quantity of incident light falling on the photodiode PD with no afterglow of the pixel.

[0036] Figure 7 shows the output characteristics of the sensor signal, which were obtained by changing the quantity of incident light L_s falling on the photodiode. The diagram indicates that the sensor signal has a complete logarithmic output characteristic at the sensor current of $1E-13A$ or more (i.e. $1E$ minus $13A$ through $1E$ minus $6A$, as shown). It is also found that the output sensor signal is not logarithmic at the sensor current of less than $1E-13A$ but this does not cause afterglow.

[0037] The diagram also indicates that the output characteristic shown at (a) in Fig. 7 can be obtained by adjusting the threshold of the low level L to which the drain voltage V_D of the transistor Q_1 must be changed over and by decreasing the drain voltage until the transistor Q_1 reaches the state of completely low resistance. On the contrary, the normal logarithmic output

characteristic shown at (b) in Fig. 7 can be obtained by setting the control voltage V_D to the same value as the gate voltage V_G .

[0038] Therefore, the output characteristic (a) of Fig. 7 is free from the afterglow effect but the light signal detecting sensitivity is decreased with a small quantity of incident light while the output characteristic (b) of Fig. 7 may have a high detection sensitivity at a small quantity of incident light but is accompanied by a remarkable afterglow. In other words, there is a trade-off relation between the detection sensitivity and afterglow.

[0039] Therefore, it is desirable to adjust the drain voltage V_D of the transistor to a value in an intermediate region between the output characteristic (a) shown in Fig. 7 and the logarithmic output characteristic (b) as shown in Fig. 7 on the following condition:

[0040] For the applications where the afterglow is acceptable, the drain voltage of the transistor must be set to a value at which the higher detection sensitivity is obtained. On the contrary, for the applications where the afterglow must be avoided, the drain voltage must be set to a value at which no afterglow may be produced. In practice, the drain voltage V_D is adjusted to a value selected for obtaining the highest detection sensitivity in view of the actual application and the actual permissible afterglow.

[0041] The present invention is directed to an image sensor consisting of a number of the above-described light sensor circuits arranged to form a matrix of pixels (i.e. light sensor circuits), wherein sensor signals from respective pixels are read by scanning in a time series and the pixels can be initialized in time adapted to the readout-scanning of respective sensor signals.

[0042] Figure 8 illustrates an image sensor according to an embodiment of the present invention.

[0043] The image sensor is composed of 4x4 pixels D11-D44 arranged in a matrix of pixel circuits, in which pixel lines are selected one by one with respective selecting signals LS1-LS4 successively output from a pixel line selecting circuit 1 and pixels in each selected pixel-line are readout one by one as respective sensor signals in such a manner that selecting signals DS1-DS4 successively output from a pixel selecting circuit 2 turn on corresponding switches SW1-SW4 to read sensor signals in a time series. In Fig. 8, numeral 4 designates a power source for gate voltage VG of the transistor Q1 and numeral 6 designates a power source for a drain voltage VD of the transistor Q1.

[0044] The image sensor of the present invention is provided with a voltage switching-over circuit 5 by which a drain voltage VD of each transistor Q1 for each pixel is changed from a normal high-level H to an initializing lower level L by the effect of a specified timing pulse when selecting each line of pixels.

[0045] The operation of the above-described image sensor according to the present invention will be described with reference to Figure 9 showing a time chart of signals generated at respective portions of the image sensor.

[0046] Once the pixel-line selecting signal LS1 reaches the high level H, the first pixel line including pixels (light sensor circuits) D11, D12, D13 and D14 is selected and, during a specified period T1 of the signal LS1 remaining at the high level H, pixel selecting signals DS1-DS4 successively reach the high level H to start the successive reading of sensor signals from pixels D11, D12, D13 and D14.

[0047] As soon as the pixel-line selecting signal LS1 was changed to the low level, a next pixel-line selecting signal LS2 is changed to the high level H to select the second pixel line containing pixels D21, D22, D23 and D24. For a specified period (T1) of the signal LS2

remaining at the high level, the pixel selecting signals DS1-DS4 successively reach the high level H to start the successive reading of sensor signals from pixels D21, D22, D23 and D24.

[0048] Similarly, with the pixel-line selecting signals LS3 (LS4) changed to the high level H, the third (fourth) pixel line is selected and then, for a specified period (T1) for which the signal LS3 (LS4) remains at the high level H, the pixel selecting signals DS1-DS4 successively reaches the high level H to start the successive reading of sensor signals from pixels D31, D32, D33 and D34 (D41, D42, D43 and D44).

[0049] When the pixel-line selecting signal LSI was changed to the low level L, the drain voltage VD1 for the pixels D11, D12, D13 and D14 in the first selected line is turned to the low level for a specified period T2 to make the pixels initialized and prepared for the next cycle of reading sensor signals, which cycle will be performed with elapse of one cycle time T3.

[0050] When the pixel-line selecting signal LS2 was changed to the low level L after the period T1, the drain voltage VD2 for the pixels D21, D22, D23 and D24 in the second selected line is turned to the low level for the specified period T2 to initialize the pixels for the next sensor-signal reading cycle to be performed with elapse of one cycle time T3.

[0051] Similarly, once the pixel-line selecting signal LS3 (LS4) was changed to the low level L after the period T1, the drain voltage VD3 (V4) for the pixels D31, D32, D33 and D34 (D41, D42, D43 and D44) in the third (fourth) selected line is turned to the low level to initialize the pixels for the next sensor-signal reading cycle to be performed with elapse of one cycle time T3.

[0052] Although the drain voltage VDX is turned to the low level L to initialize each light sensor circuit with the pixel-line selecting signal LSX (X=1-4) decreased to the low level

with elapse of the period T1, the initializing timing may be within the duration T4 for which the pixel line selection is paused with the pixel-line selecting signal being at the Low level L.

[0053] In initializing each pixel in the image sensor shown in Fig. 8, all pixels D11 to D44 may be initialized at the same time before reading sensor signals from respective pixels.

[0054] Figure 10 illustrates a time chart of signals generated at respective portions of the image sensor when all pixels D11-D44 are initialized at the same time.

[0055] The timing of occurrence of signals at respective portions is decided by driving the pixel-line selecting circuit 1, the pixel selecting circuit 2 and the voltage switching-over circuit 5 under the control from a control circuit (not shown).

[0056] Initializing each pixel at the timing adapted to scanning for reading each sensor signal may avoid an over or short charge-accumulating duration for a whole system of the image sensor.

[0057] Thus, according to the present invention, it is possible to realize an image sensor having a wide dynamic range of its logarithmic output characteristic without causing the afterglow of the pixels.

[0058] Figure 11 illustrates an image sensor according to another embodiment of the present invention.

[0059] In this case, sample-and-hold circuits SH1-SH4 are provided on the output side of pixels in respective selectable pixel lines.

[0060] As shown in Fig. 12, a sample-and-hold signal SHS is given to each of the sample-and-hold circuits SH1-SH4, which successively holds sensor signals for every pixel of one pixel line selected.

[0061] The image sensor thus constructed can stably output sensor signals from respective pixels in the selected pixel line.

[0062] An image sensor according to an aspect of the present invention uses a plurality of light sensor circuits arranged to form a matrix of pixels-circuits, each of which produces in a photoelectric converting element a sensor current proportional to the quantity of light falling thereon and converts the current into a voltage signal by a MOS type transistor having a logarithmic output characteristic in a weak inverse state. Each light sensor circuit is further provided with means for changing the drain voltage of the transistor to a value lower than a normal value for a specified time to initialize the circuit before detecting a light signal by removing a charge accumulated in a parasitic capacity of the photoelectric converting element, thereby obtaining a sensor signal without the effect of a residual charge.

[0063] An image sensor according to another aspect of the present invention is composed of a number of light sensor circuits arranged to form a matrix of pixels-circuits, each of which produces in a photoelectric converting element a sensor current proportional to the quantity of light falling thereon and converts the current into a voltage signal by using a MOS type transistor having a logarithmic output characteristic in a weak inverse state. Each light sensor circuit is further provided with a voltage switching-over circuit by which the drain voltage of the transistor is turned to a value lower than a normal level for a specified time to remove a charge accumulated in a parasitic capacity of the photoelectric converting element before detecting a light signal, thereby obtaining a sensor signal corresponding to the quantity of incident light even with a rapid change of the sensor current. This eliminates the possibility of occurrence of afterglow of every pixel with a small quantity of light falling thereon.

[0064] An image sensor according to a further aspect of the present invention is composed of a number of light sensor circuits arranged to form a matrix of pixels, a pixel-line selecting circuit for successively selecting pixel lines and a pixel selecting circuit for successively selecting pixels in each selected pixel line, wherein sensor signals can be scan and read from respective pixels in a time series. This image sensor is further provided with voltage switching-over circuits one for each light sensor circuit (pixel) , by which the drain voltage of each MOS type transistor is turned to a value lower than a normal value for a specified time to remove a charge accumulated in a parasitic capacity of the photoelectric converting element before selecting each pixel line. The initialization of each pixel can be performed at timing adapted to reading of each sensor signal.